and sulfate removal rates in the river. We used breakthrough curves obtained from subsurface sampling locations in close hydrologic contact with the stream to quantify subsurface nitrate removal rates not limited by diffusion.

H51G-05 1135h

Nitrogen Isotopic Fractionation by In-Stream Populations of Ammonia-Oxidizing Bacteria

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Nitrogen cycling in the upper Illinois River basin is heavily impacted by agriculture and the application of nitrogenous fertilizer. Nitrate concentrations in many of its tributaries in Indiana (e.g. Iroquois River, Sugar Creek) have large seasonal fluctuations, ranging from less than 10 micromolar in the late summer to greater than 650 micromolar in the spring. We have performed a series of experiments to study the impact of this seasonal influx of nitrogen on bacterial populations and corresponding biogeochemistry related to nitrogen cycling in small streams. In this study, microcosms were used to measure nitrogen isotopic fractionation during nitrification by natural communities of water-column bacteria amended with NH_4^+. The in-stream nitrifier communities were also studied using molecular biological techniques to expand a previously observed correspondence between ammonia monooxygenase sequence and isotopic fractionation. The isotope effect (ϵ) for ammonia oxidation (14 permil) in June was calculated from a Rayleigh model based on changes in $\delta^{15}NH_4^+$ during the microcosm incubation. Supporting analyses indicated that NH_4^+ was oxidized primarily to NO_2^-. The evolution of the $\delta^{15}N$ in the $[NO_2^- + NO_3^-]$ pool was also consistent with an ϵ of 14 permil for ammonia oxidation. This value is similar to previous reports of NH_4^+ fractionation in the Chesapeake Bay and for *Nitrosomonas* species cultured from low- NH_4^+ environments, but is significantly different from *Nitrosomonas* species cultured from eutrophic environments. These results introduce a relationship between microbial community structure and isotope fractionation that may be used to better understand nitrogen cycling in streams.

H51G-06 1150h

Estimates of Nitrogen Removal in U.S. Streams and Reservoirs from the SPARROW Watershed Model

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Greater understanding is needed of the biotic and abiotic processes that remove nitrogen (N) from streams and reservoirs to quantify transport to downstream coastal waters where eutrophication is a major concern. Recent studies have improved estimates of N removal rates (e.g., denitrification, biological uptake) over small spatial scales in low-order streams. However, limited knowledge of the factors that explain the large variation in literature removal rates has made it difficult to accurately predict N transport through the range of stream and reservoir sizes that link sources to downstream waters. Spatially referenced watershed models (SPARROW) have been used to statistically estimate long-term mean-annual rates of total nitrogen removal in streams and reservoirs over large spatial scales. These rates are estimated as a function of physical and hydraulic properties (channel depth, water travel time) that influence the contact and exchange of water with benthic sediment. We recently refined our SPARROW model structure with expanded descriptions of climatic, topographic, and other surficial features of terrestrial and aquatic landscapes. We find that the net rates of N removal decline from about 0.3 day-1 of water travel time in streams with depths less than 0.5 meters to negligible quantities in large rivers (greater than 4 meters). These rates are generally consistent with those of earlier regional and national SPARROW models and with measured rates from the literature (adjusted for water travel time) over the reported range of stream depths. A settling velocity of approximately 8 meters year-1 is estimated for lakes and reservoirs and agrees well with literature rates for lakes where denitrification is the predominant removal process. We applied these removal rates within the SPARROW stream and reservoir network to estimate the regional-scale N transport and delivery to U.S. coastal waters.

URL: http://water.usgs.gov/nawqa/sparrow

H51G-07 1205h

The impact of changing land use practices and climate variability on nitrate export by the Mississippi River

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The increased use of nitrogen fertilizer in the Mississippi River Basin since the 1950s has been blamed for declining water quality, the degradation of aquatic ecosystems and the growth of a seasonal hypoxic zone in the Gulf of Mexico. In this study, we use the IBIS terrestrial and agro-ecosystem model and the HYDRA aquatic transport model to examine how agricultural practices and climate variability influenced terrestrial and aquatic nitrogen cycling across the Mississippi Basin and the export of nitrate to the Gulf. The modeling system accurately depicts the observed trends and interannual variability in nitrate export by the Mississippi River ($r^2 > 0.8$), and several of the major tributaries, between 1960 and 1994. The challenge of simulating nitrate export from the western sub-basins highlights the key role of nitrogen retention processes like denitrification. The simulations demonstrate that three factors led to the doubling of nitrate export by the Mississippi River since 1960: (1) an increase in fertilizer application rates, particularly on corn; (2) the expansion of soybean cultivation; and (3) an increase in runoff across the basin. By the early 1990s, crops alone may have accounted for almost 90% of the nitrate leached to the river system, despite representing only 20% of the watershed area. The majority of the nitrate exported to the Gulf now appears to originate from several “hot spots”, including a stretch of the Corn Belt’ across Iowa, Illinois and Indiana. The relative contribution of such heavily fertilized lands is even greater during wet periods, due to high leaching losses and relatively low in-stream nitrogen retention. These findings demonstrate that the effort to reduce the flux of agriculturally-derived nitrogen to the Gulf of Mexico could be further complicated by increasing variability in climate.

H51H MCC: 3024 Friday 1020h

Interactions Between Fluids and Fractures III *(joint with T, V, NG, MR)*

Presiding: **L C Murdoch,** Clemson University**; L Germanovich,** Georgia Institute of Technology

H51H-01 1020h

Complex Dispersion in Simple Fractured Media

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Complex dispersion can develop in simple networks of fractured media. Numerical studies, involving modeling flow and particle transport through networks, were conducted to understand complex dispersion in the context of more variable networks and to evaluate the scaling between dispersion and characteristics of the network. Simulation trials examined how changes to the orientation of the overall network, fracture aperture, fracture connectivity, and fracture length influenced mass transport. The grid orientation effect inherently gives rise to the complex, non-Fickian dispersion. Spreading caused by variability in aperture and connectivity produces the more familiar, elliptical pattern of spreading. In the various model trials, we created situations where either or both of these spreading mechanisms could dominate. When both grid orientation and heterogeneity effects were comparable, particle swarms took on a curious hybrid shape reflecting the outcome of two different spreading mechanisms. With sufficient heterogeneity, the grid-orientation effect was swamped and disappeared.

H51H-02 1035h

Investigation of Matrix Diffusion in Deep Hot-Dry-Rock Reservoirs Using Single-Well Injection-Withdrawal Tracer Tests

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The dimensioning of geothermal energy usage from deep hot-dry-rock reservoirs requires knowledge of the effective heat exchange surface between liquid and solid phases. Tracer tests are an appropriate technique for the investigation of this surface since matrix diffusion and hence tracer transport is a function of the effective contact area. However, investigations within such reservoirs are difficult: Usually only one borehole is available due to economic restrictions, high temperature stimulates tracer decay, and matrix diffusion is masked by hydrodynamic dispersion within the advective pore space due to heterogeneity. To overcome these difficulties, an experimental concept was developed. It is based upon the synchronous application of several non-retarding tracers with different diffusion coefficients. Using the single-well injection-withdrawal (SWIW) technique, the effect of hydrodynamic dispersion is partially reversed, while the effect of molecular matrix diffusion is enhanced. Hence the differences between the tracer breakthrough curves are due to different matrix diffusion. Knowing the diffusion coefficients of the individual tracers, an effective contact surface between liquid and solid phases can be estimated. Since each tracer is subjected to the same advection and dispersion, the formation heterogeneity is of minor importance and the different transport behavior can be attributed to the molecular diffusion only. The tracers under investigation are sulfonated naphthalene-formaldehyde condensates (SNFC) and the corresponding monomeres. These compounds are available in various chain lengths, spanning a range of aqueous diffusion coefficients. Modern HPLC methods enable their analysis down to a ìg/l level. Since SNFC are environmentally benign, they could be recently applied within the unsaturated soil zone, in a shallow aquifer as multi-tracer mixture, and in geothermal systems. The experimental approach and first results are presented.

H51H-03 1050h

The role of Peclet number on the alteration of variable aperture fractures by dissolution: A comparison of physical experiments with computational simulations

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In a fracture in which the fluid and rock surfaces are not in chemical equilibrium, reactions between the flowing fluid and host rock can lead to dissolution and/or precipitation of minerals along the fracture surfaces. The resulting changes in fracture aperture can lead to alteration of fracture permeability. Local rates of precipitation/dissolution are controlled by surface reaction rates and the transport of reactants by advection and diffusion within the fracture. For the case of fast surface reactions, the local Peclet number (Pe = $V\langle b\rangle/D_m$, where V is the mean fluid velocity, $\langle b\rangle$ is the mean fracture aperture, and D_m is the molecular diffusion coefficient of dissolved minerals), which is the ratio of the time scales of advection and diffusion, will control the fracture-scale patterns of mineral dissolution and precipitation. We compare results from a pair of physical dissolution experiments at different initial values of Pe (Pe_o) to dissolution simulations using a coupled reactive transport model based upon the two-dimensional Reynolds equation for flow through variable aperture fractures. We fabricated transparent analog fractures by mating a 9.9 x 15.2 cm textured glass plate with flat potassium-dihydrogen-phospate (KDP) crystals. Because only the KDP surface dissolved during the experiments, it was possible to replicate the initial conditions for each experiment. In addition, the transparent fracture allowed us to use light transmission techniques to directly measure the fracture aperture during experiments at high-resolution (0.083 x 0.083 mm pixels). For Pe_o=54, distinct dissolution channels formed, while for Pe_o=216, we measured minimal channeling and a reduction in short-wavelength aperture variability. Computational simulations using the initial measured aperture fields yield qualitatively similar dissolution patterns. In both the experiments and simulations, the nature of the dissolution patterns strongly influenced the relative increase of fracture permeability. The experiments demonstrated that a 110% increase in mean fracture aperture resulted in estimated permeability increases of 440% and 640% for the Pe_o=54 and Pe_o=216 experiments, respectively. The simulations are in close agreement with the experiments up to about 50% growth in mean aperture after which the simulations predict faster increases in permeability than we observed experimentally.

H51H-04 1105h

Experimental Observation of Flow, Dissolution and Precipitation in Fractured Carbonate Rocks

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A series of laboratory experiments was carried out in order to study permeability fields and flow patterns induced by simultaneous precipitation and dissolution processes in fractured carbonate rocks (calcareous sandstone and dolomite). In particular, the influence of fracture orientation relative to the direction of flow was studied; isolated and through-flow fractures were each considered. Dissolution and precipitation are two of the most important processes affecting groundwater chemistry, and they can significantly modify the physical and chemical properties of fractured media. Two types of linear flow experiments were performed: (1) a 2D flow cell containing 1 cm thick rock slices was used for single fracture experiments; and (2) 3D rock cores containing fractures were investigated to study the interplay of flow between fractures and porous host rock. In both experimental systems, different acid mixtures were injected at various flow rates. Changes in head gradient were recorded at specific time intervals during the experiments, and the overall hydraulic conductivity was then calculated as a function of time. The outlet effluent was collected and analyzed for different ion concentrations in order to calculate porosity changes (based on molar volume of the components) during the experiments. The evolution of hydraulic conductivity in the fractured rock samples, due to competition among flow, precipitation and dissolution processes, was found to display a variety of possible behaviors. In all cases, the flow through the system ends either by clogging of the porous host rock and/or the fracture(s) (due to precipitation and mechanical movement of particles) or by collapse of the rock sample (due to dissolution). Different structures of precipitate were found in the porous host rock, and in both isolated fractures and through-flow fractures.

H51H-05 1120h INVITED

DECOVALEX - an International Cooperative Research Project on Coupled Thermo-hydro-mechanical Processes in Fractured Rocks

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The international cooperative project DECOVALEX (acronym for DEvelopment of COupled THM models and their VALidation against EXperiments) was established in 1992 by national agencies involved in nuclear waste disposal. The aim of this project is to develop and test models capable of simulating coupled thermo-hydro-mechanical (THM) processes. Over the last ten years, about 16 research teams from 10 countries have participated in this joint effort. The project objectives include: a. support development of computer simulators for THM modeling; b. investigate and implement suitable algorithms for THM modeling; c. compare model calculations with results from field and laboratory experiments; d. design new experiments to support code development; e. study the application of THM modeling to performance and safety assessment. A large number of benchmark tests (BMT) and test cases (TC) have been studied within the project. BMTs are hypothetical problems used for investigating the behavior of individual coupled THM processes, using alternative conceptual and numerical models by different teams. TCs are laboratory and field experiments that were analyzed to advance our understanding of THM processes and whose data were used to test computer models. A number of large-scale, multiyear experiments have been studied within the project, including: a. multiple borehole tests for shaft excavation design at Sellafield, UK; b. THM experiment on the bentonite-rock system at Kamaishi Mine, Japan; c. full scale bentonite-rock test (FEBEX) at Grimsel Underground Research Laboratory, Switzerland; d. Drift Scale Heater Test (DST) in the Exploratory Studies Facility at Yucca Mountain, USA. The talk will present an overview of the ten-year project by highlighting a few of the main results and lessons learned.

URL: http://www.decovalex.com

H51H-06 1135h

Using Changes in Fracture Aperture During the Interpretation of Hydraulic Well Tests

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Fractures either dilate or contract in response to head changes during hydraulic well tests. We are measuring those changes in aperture in an effort to increase the information obtained from well tests. The measurements are made with a borehole extensometer temporarily anchored to the walls of an open borehole at two locations. An LVDT measures axial displacement between the anchors and those measurements are recorded along with pressure and temperature during a well test. Current investigations have focused on isolated flat-lying fractures, so axial displacements are assumed to equal changes in aperture. The current design of the extensometer can resolve displacements on the order of several tenths of a micron. Limiting sensitivity of the device to changes in temperature has been an important aspect of ensuring accuracy. Field tests are conducted on fractures identified using caliper and camera logs, and intact borehole intervals are tested for control. Preliminary tests have made use of a borehole cutting flat-lying fractures in biotite gneiss, where the fracture spacing and degree of weathering decreases with depth. Results show that the characteristics of the fractures change with depth: average normal compliance decreases from 0.5 micron/kPa to less than 0.05 micron/kPa, and the effective transmissivity decreases as depth increases from 23 m to 29 m. Normal compliance can be used to determine specific storage, suggesting that the displacement measurements can be used to determine aquifer storativity using a test conducted at a single well. Moreover, fracture compliance of the observed magnitudes implies that the fracture aperture, and thus the transmissivity, may change markedly during well tests where changes in head are significant. More detailed interpretations of the results are being made using a model that considers fluid flow along a deformable fracture embedded in porous material. Inverting the model using transient displacement data provides an approach for deriving information about the in situ dimensions and deformation characteristics of fractures that go beyond what can be determined from hydraulic measurements alone.

H51H-07 1150h

Mapping of hydraulic fractures from tiltmeter measurements

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In considering the problem of inverse modeling of tiltmeter data for hydraulic fracture mapping, we address the issues of selecting the elastic model to represent the hydraulic fracture and limitations imposed by distance and fracture size on the information that can be recovered about the fracture. A tiltmeter measures, at its location, the changes in the surface inclination in two orthogonal directions. These inclinations are a direct measure of the horizontal gradient of the vertical component of the displacement field. Since advances in instrumentation in the last two decades, this type of apparatus have become extremely precise and can detect inclination changes down to a nanoradian. The simplicity of tiltmeter measurements has attracted interest not only in geophysics, but also in the petroleum industry. The idea of using tiltmeters to monitor hydraulic fractures can be traced back to the paper of Sun 4 and is now a commercial service offered to the petroleum industry 5. However, the modeling and associated inverse problems required to analyze tiltmeter data raise difficult questions. The object(s) (fault, dyke, fracture) responsible for the recorded tilt are often modeled by finite Displacement Discontinuities, also called dislocation models. The validity of this type of model has been extensively discussed 3, 1 and many solutions for different configurations can be found in the literature. We show that it is possible to construct the solution for any type of dislocation model from the fundamental solution for an infinitesimal Displacement Discontinuity tensor. The eigenstrain theory 2 is used to obtain this fundamental solution from the Green's function for the desired elastic domain (e.g. full or half space). Comparisons with known solutions demonstrate the flexibility of such method. We then focus on the problem of obtaining information about the orientation and size of an opening mode hydraulic fracture from the measured tilt field. One important problem is the identification of all the dimensions of the fracture model (length, width). The ability to obtain these parameters is controlled by limits, expressed in terms of the distance between the measurements and the fracture compared to the size of the fracture itself. The value of this ratio provides a condition that must be met before the fracture length-scales can be resolved. Determination of the fracture orientation is then investigated using a spatial Fourier Transform on the data set. This procedure highlights the requirement on the measurement array needed for a reliable identification: extension, number of tiltmeters, relative angle between the array and the fracture plane.

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H51H-08 1205h

Critical Role of Stress in Flow of Fluids in Fractures

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The role of stress in controlling fluid flow in fractured rock will be examined using numerical (discrete element) models. In any well-connected fracture network there is a critical stress state at which the flow changes from being fairly pervasive through the fracture network to being both enhanced and highly localized in parts of the network. This critical point is produced by the self-organisation of slip and opening on some fractures. The critical stress state has been

evaluated for different loading paths and is found to be largely controlled by a simple parameter, the driving stress ratio (R), where R = 2 x (fluid pressure - mean stress) / (differential stress). In numerical models of highly fractured rock, the critical stress state R_C can be demonstrated to depend mainly on the frictional properties of the fractures, with other parameters (e.g. fracture geometry, density and rock rheology) controlling the form of the resulting deformation and localization of fluid flow. In most cases the critical driving stress ratio (R_C) is between -2 and -1.5. A common feature of a critically stressed fracture network is the localized nature of the fluid flow. In situ stress measurements, especially those from deep boreholes and producing oil reservoirs, indicate that driving stress ratios, R, are -2 or higher. In some cases where stress changes locally, either naturally or through human intervention, R remains constant. These observations agree well with numerical models and strongly support the idea that much of the upper crust is maintained at or close to the critical stress state. In such cases, localization of flow should be characteristic.

H52A MCC: Level 2 Friday 1330h

Fluvial Geomorphology Posters

Presiding: **E B Safran,** Lewis and Clark College**; E Wohl,** Colorado State University

H52A-1138 1330h POSTER

Channel Initiation Processes in Basalt and Sandstone Lithologies in Southwest Washington

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A persistent problem for managers of headwater streams has been accurately identifying where these headwater channels begin on the hillslope and determining the physical extent of the channel network. This problem is exacerbated by the relatively few published field data on both channel-head locations and initiation processes in forested landscapes of different lithologies. Several workers have presented the theory that channel-head locations are a function of an inverse slope-drainage area relationship. We hypothesized that channel-head locations in a fine-grained basalt lithology would be independent of slope. In sandstone, we expected channel-head locations to follow the inverse slope-drainage area relationship. In addition, we hypothesized that seasonal migration of surface water presence would reflect a near-surface hydrologic process whereas surface water flowing from the same location throughout the year would reflect a groundwater control. Seventy-eight channel-heads were mapped using a high resolution Global Positioning System in basalt and sandstone lithologies in southwest Washington. Source areas for these channel-heads ranged between 600 m^2 and 50,000 m^2 and local slopes ranged between 15% and 80%. The upslope extent of surface water was monitored and mapped for 14 basalt and 20 sandstone streams. Watersheds were monitored monthly from February through November 2003. Initial analyses have indicated that local slope does not correlate with channel-head locations in either basalt or sandstone lithologies. However, contributing areas with similar local slopes were significantly larger in basalt compared to certain sandstone lithologies. Observations from the surface water mapping suggest that the channel initiation processes within the basalt lithology are groundwater controlled versus the near-surface hydrologic control observed within the sandstone lithology. As a result, underlying lithology remains a major control on processes driving channel initiation and channel-head locations in high-gradient, lowland watersheds.

H52A-1139 1330h POSTER

Channel Initiation and Competition in Tidal Environments

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Numerical simulations are presented on the initial formation and on the competition of tidal channels evolved within youthful salt marsh environments. We present a model that simulates the evolution of tidal channel cross sections, by coupling calculations of bottom shear stresses due to tidal motions with erosion, taking into account the deposition of cohesive and noncohesive sediments. The simulations characterize the morphodynamic evolution of a reference cross section composed of incipient channels and of marsh surface zones. The discharges that shape the section vary in time as a surrogate of the tidal level with a quasi-static model. Wetting and drying cycles are therefore considered. We analyze, at first, the driving factors which lead to the actual observed channel cross sections in tidal basins, starting from the initial channel formation to their long term morphodynamic evolution. In particular, it is shown that large temporal gradients of leading flow rates induce important temporal variabilities of channel geometry in time. The local and temporary evolution of tidal channels, dictated by tidal flow rates, allows the identification of the chief landscape forming discharges. In the second part of our study we simulate the competition of tidal channels evolving within an assigned tidal flat. In these simulations the calculation of the characteristic distance between adjacent forming channels makes it possible to study the drainage density of salt marshes.

H52A-1140 1330h POSTER

Is the Profile of the Colorado River in the Colorado Plateau in Equilibrium With Bedrock?

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The Colorado River sets the pace for the erosion of the Colorado Plateau and part of the Rocky Mountains, and the evolution of its long-profile may hold the key to resolving debate over the region's late Cenozoic erosional and tectonic history. Significant reach (10 km) and canyon-scale (100 km) gradient variations occur along the modern profile of this mixed bedrock-alluvial river, and there are multiple hypotheses for the controls on its gradient: 1) knickzones related to active tectonics in western Grand Canyon, 2) coarse bed material from tributary side-canyons, and 3) bedrock resistance as a direct control with respect to channel substrate or an indirect control in terms of hillslope processes in tributary catchments and the production and comminution of bed material. The goal of this study is to test for a spatial relation between hydraulic driving forces and bedrock resisting forces at reach and canyon-scales within and between Glen and Grand canyons. The river encounters diverse rock types that vary in hardness and fracture density. Field and GIS results aimed at testing the bedrock resistance hypothesis for Glen and Grand canyons indicate a spatial relation between rock-mass strength (RMS) and channel gradient. Reach-scale gradients vary as much as a factor of 20 through Grand Canyon, with steep reaches having significantly higher compressive strengths and wide fracture spacings. Glen Canyon, on the other hand, has dramatically lower channel gradient, weaker RMS properties, and reaches with steep gradients that do not correlate to either debris fans or changes in bedrock type but do coincide with geologic structures. The presence of a bedrock or debris-fan frequency correlation to the majority of gradient variations argues against tectonic origins of knickzones and suggests a relation between bedrock resistance and the profile of the Colorado River exists. However, when these results are combined with the distribution of tributary debris fans and their control on the channel organization as detailed by other workers in Grand Canyon, there is a complex spatial correlation between bed material, rock-type, and channel gradient, preventing the direct inference that the river is in equilibrium with bedrock.

H52A-1141 1330h POSTER

Knickpoint retreat and landscape disequilibrium on the James River from the Piedmont through the Valley and Ridge, central Virginia, USA

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Several lines of evidence indicate landscape disequilibrium in the James River basin in central Virginia. The river longitudinal profile possesses pronounced convexities and apparently migratory knickzones. Along much of its length, it flows in a narrow inner valley incised into a discontinuous, low-relief upland. In the inner Piedmont, the 150 m wide river channel occupies an incised valley that can be as little as 600 m wide and 75 m deep. Broad fluvial terraces are often found capping the high topography directly adjacent to the valleys, and we use these disconnected terraces to reconstruct paleo-river profiles spanning 200 km in the Piedmont. These high, extensive terraces disappear in the James River Gap through the Blue Ridge, but reappear with less distinction in the carbonate rocks of the Great Valley. The river remains incised within the Great Valley, with prominent knickzones 60-100 km above the Blue Ridge gap found on both the mainstem and tributaries. We dated terraces in the Piedmont with in-situ 10Be profiles and a depth integration technique. Dates from the highest terrace level at three locations along 100 km of the river are 1 m.yr., suggesting rapid river incision rates of 55 m/m.yr. We also have documented exceptionally high incision rates along a tributary in the Great Valley. This dating suggests disequilibrium erosion was initiated and has persisted here during the late Quaternary. Assuming the incision is accomplished largely by knickpoint retreat, the dates suggest past retreat rates of up to one m/yr in the Piedmont and 250 m/m.yr. between the outer Piedmont and the Great Valley. We have two hypotheses for how this recent incision was triggered: 1) response to flexural-isostatic uplift generated by drainage basin capture and associated denudation and/or 2) the shift to more rapid climate fluctuations in the early Pleistocene. Additionally, we suggest two interpretations for the generation of the extensive high terrace surfaces. They may be valley floor remnants of a broad alluvial upland incised by a migrating knickpoint, or remnants of a broad valley floor developed at the base of knickpoints that have now migrated upstream along the profile.

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Quantifying the Convexity of Waterfalls Along the Niobrara River, Cherry, Keya Paha, and Brown Counties, Nebraska

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Numerous waterfalls are present along the spring branch canyons of the Niobrara River, downstream of Cornell Dam, Valentine, Nebraska. Although the sizes of the waterfalls are variable, a majority of the waterfall faces have a convex outward geometry. In order to gain a better understanding of the processes responsible for the development of this profile, it is useful to quantify the convexity of the waterfall face. Due to the rugged topography of the spring branch canyon environment, traditional techniques, such as pin-flag and tape measurements are not practical and even dangerous. The waterfall faces are often greater than 3 meters high, steep, and algae covered. The spring branch canyon walls are also steep with actively creeping scree slopes along the bases. Therefore, due to this topography there is no easy way to access the waterfall faces for accurate measurements. The measurement problem was overcome by using a hand-held laser meter mounted on a tripod. A baseline was established below the waterfall face. The length of the baseline was measured using the hand-held laser meter. Measurements were taken on distinct features across the waterfall face and sidewalls from both endpoints of the baseline. The angle of the laser off the baseline and off the horizontal were measured using a compass with mirror. With these measurements, the waterfall faces profile relative to the baseline was reconstructed. A hand-held laser meter is an important tool for measuring waterfalls and other geomorphic features in hazardous environments because measurements can be taken from a safe location. It is possible for one person to take accurate measurements. New baselines can readily be established to measure relative erosion along the waterfall face over time.

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The Origin of Convex Waterfalls Along the Niobrara River by Valentine, Nebraska

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